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Towards the operational assimilation of Doppler Wind at regional scale in Météo-France

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1 Introduction

Météo-France is currently developing a Numerical Weather Prediction (NWP) system at convective scale that will be hopefully run operationally at the beginning of 2008. This system, called AROME, will cover the French territory with a 2.5 km horizontal resolution and will use a complete data assimilation system derived from the ALADIN 3Dvar that is operationally running at Météo-France at regional scale (Fischer et. al, 2006 (F2006 hereafter)). In this context, radial velocities and reflectivities observed by the ARAMIS Doppler radar network (11 radars so far) will play a key role by providing information about the low level horizontal wind and the precipitation patterns within precipitating systems over a wide part of France (Fig. 1). As a preliminary step towards the use of radial velocities in the AROME project, an observation operator, that allows to simulate such quantities from the model variables, has been developed in the ALADIN 3Dvar to investigate the impact of their assimilation for short range weather forecast at mesoscale. This paper discusses the set up to assimilate Doppler wind in the latter system and the sensibility of the observation operator to each of its components.

2 The operational ALADIN 3DVar

To perform short-range forecasts over Western Europe, Météo-France is running operationally the limited area model ALADIN with four daily updates towards observations using a 3Dvar data assimilation system (F2006). This system includes, among other observation types, data from ground based stations, aircrafts, radiosoundings and radiances from geostationary and polar orbiting satellites (Montmerle et. al (2006)).

The variational code of the 3Dvar is based on an incremental formulation originally introduced in the ARPEGE/IFS global assimilation system (Courtier et. al, 1994) and uses an ensemble based background error covariances matrix (Ştefãnescu et. al, 2005) (see F2006 for more details) that allows to represent the effect of the analysis and of the background, which is a 6 h forecast, in an accurate way considering the 10 km horizontal resolution.

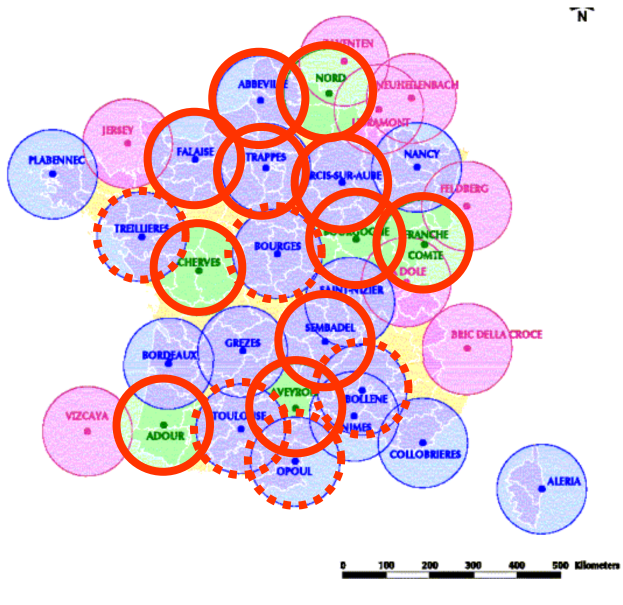

***Fig. 1** : The French ARAMIS radar network. Bold circles show Doppler radars, dashed circles Doppler radars planned for 2007.*

3 The radial wind observation operator

In a variational assimilation system, one tries to find a model state (the analysis) that minimizes a cost function that measures the departure of the model state to a previous forecast (the background) and to observations. The latter term is written in the observation space, which implies the computation of an observation operator that interpolates horizontally and vertically the control variables to the observation locations and that simulates the observed quantities. The geometrical part of the observation operator used in this study, displayed in Fig. 2, follows closely the hypothesis of Salonen et. al (2003) (S2003 hereafter) and involves:

- Bi-linear interpolations of the model horizontal wind components u and v at the observation locations

- Horizontal projection of u and v towards the radar

$$v_h = u \sin\varphi + v \cos\varphi \qquad (1)$$

where φ is the azimuth angle of the radar beam.

- Computation of the radial wind which is the projection of v_h on the slanted direction of the radar beam

$$v_r = v_h \cos(\theta + \alpha) \qquad (2)$$

with:

$$\alpha = \arctan\left(\frac{d\cos\theta}{d\sin\theta + a + h}\right) \qquad (3)$$

where θ is the elevation angle of the radar beam, d the distance between the target and the antenna, a the earth's radius and h the height of the radar above sea level. Eq. (2) does not consider the fall speed of hydrometeors that can, as shown in the next section, be neglected in our case because of the relatively low maximum elevation used in the network (around 14°, depending on radars). Eq. (3) follows the earth's effective radius model (a_e = 4/3 a) that makes the hypothesis that the ray path is straight over this larger earth, i.e that the refractivity varies linearly with height.

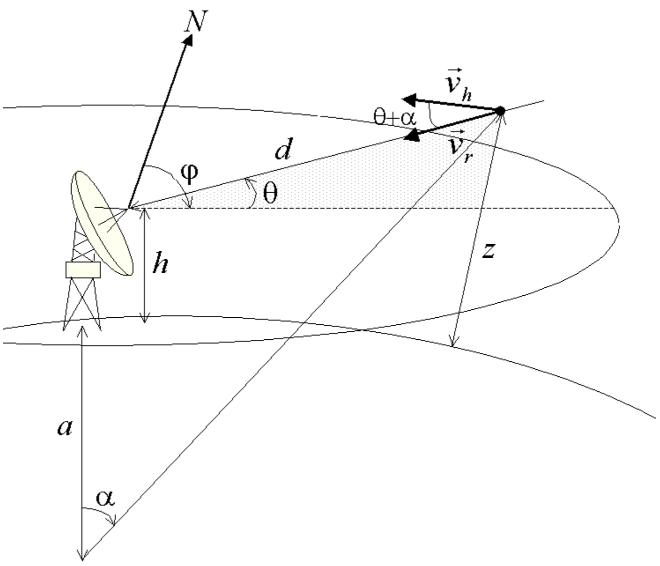

Fig. 2: The geometry used for simulating Doppler radial wind in the NWP (see text for details). Adapted from S2003.

- Broadening of the radar beam. Since radars of the ARAMIS network are characterized by differences between primary and secondary lobe maxima larger than 20 dB, the contribution of the latter within the received signal is neglected. The directivity function of the antenna for the main lobe is simulated by a Gaussian function, as in Probert-Jones (1962). This averaging function is applied vertically for gridpoints comprised between the lower and the upper limits of half-power beamwidth, for which the elevation is given by (Doviak and Zrnić, 1993):

$$\theta = \arcsin\left(\frac{(z + a_e)^2 - d^2 - a_e^2}{2da_e}\right) \qquad (4)$$

This direct observation operator has been implemented in the ALADIN 3Dvar. An example of simulated and observed radial velocities for a 1.2° elevation is displayed in Figs. 3 for a convective line that propagates southeastward over the Paris region. It has to be noted that, for this example, velocities have been preprocessed using a 7x7 km^2 median filter to reduce dealiasing errors as in Tabary et. al (2005). Good agreement is found between the two fields, which seems to indicates that i) the background field, which is a 6 hour forecast, captures well the low level wind circulation, ii) the observation operator gives reasonable results. Monitoring of time series of innovations (observed minus simulated values) will be performed in a near future to evaluate these behaviors on a longer time period and to tune the data quality control.

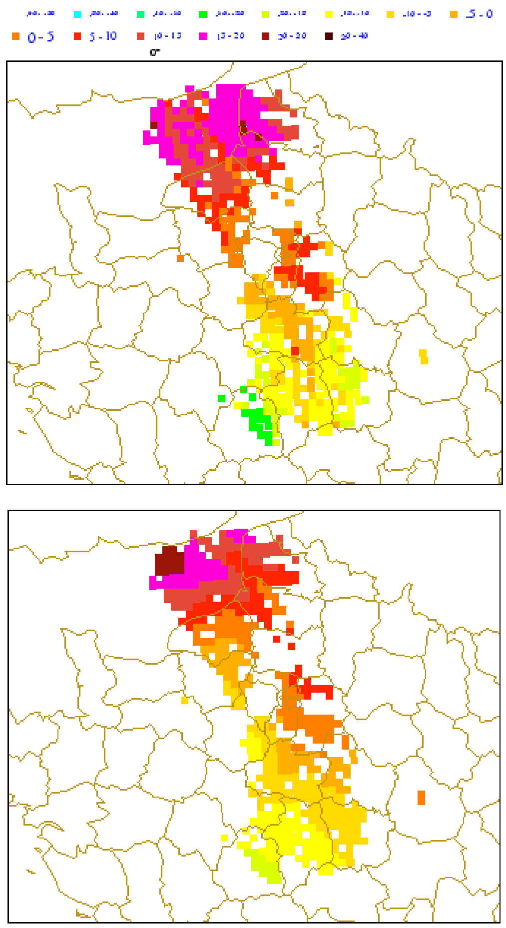

Fig. 3: Observed (top) and simulated with ALADIN (bottom) radial wind the 10th of August 2004 by the Trappes Doppler radar (Paris region).

4 Sensitivity studies

Parallel to the assimilation experiment performed with the ALADIN 3Dvar, sensitivity studies have been carried out in order to find a trade-off between accuracy and computational efficiency inasmuch as the model's sophistication enables it.

At present most observation operators for radial winds are relatively basic: the wind velocity is projected into the radial direction and the vertical velocity of hydrometeors is sometimes included (e.g., Sun and Crook , 1997). A further refinement is to weight the fall speeds by reflectivities (e.g., Wu et al., 2000). But few observation operators model the geometry of the radar beam very accurately. The observation operator described in the previous section, which is similar to S2003 and Xue et al. (2006), model the broadening of the radar beam in the vertical, but do not account for the fall velocity of hydrometeors and the weighting by reflectivities and illuminations (see Doviak and Zrnić, 1993, section 5.2, for more details). There is thus clearly a need for quantifying errors associated with each of these assumptions in a data assimilation framework.

In this view, a rather comprehensive radar simulator has been developed that takes into account the hydrometeor fall speeds, the weighting of Doppler velocities by reflectivities and illuminations, and the beam broadening in the vertical. This simulator is coupled with Meso-NH, which is a high-resolution nonhydrostatic model that uses the same microphysical scheme as AROME. This allows to access all the fields that are necessary to the simulator: three-dimensional wind components as well as cold and warm hydrometeor contents.

Experiment	Vertical broadening	Fall speed	Reflectivity weighting
E_{all}	Yes	Yes	Yes
E_{-vb}	No	Yes	Yes
E_{-fs}	Yes	No	Yes
E_{-rw}	Yes	Yes	No
E_{-vbrw}	No	Yes	No
E_{-fsvb}	No	No	/[1]
E_{-fsrw}	Yes	No	No

Table 1: *Characteristics of the sensitivity experiments.*

Sensitivity tests, described in Table 1, have then been carried out using this simulator: by neglecting some of these processes separately, the error made when a simpler simulator is used can be quantified. They are here illustrated on a severe flash-flood event that occurred on 8-9 September 2002 in south-eastern France for which radial wind observations from the Bollène radar are simulated. This S-band radar scans 13 different elevations from 0.3° to 18°. The maximum range is 280 km. Outputs are 2 km×2 km Cartesian grids. Radar simulations are performed every hour from 1600 UTC 8 September 2002 until 0600 UTC the day after.

Experiment	Mean diff. ($m\ s^{-1}$)	Std dev. ($m\ s^{-1}$)
E_{-vb}-E_{all}	-0.15	1.63
E_{-fs}-E_{all}	0.11	0.14
E_{-rw}-E_{all}	-0.33	2.53
E_{-vbrw}-E_{all}	-0.21	2.01
E_{-fsvb}-E_{-fs}	-0.29	2.09
E_{-fsrw}-E_{-fs}	-0.32	1.96

Table 2: *Mean difference and standard deviation of the difference between approximated and "perfect" formulations for Doppler velocities (see text for details).*

The statistics show that the error made when fall speeds are neglected is much smaller than errors made when beam broadening and/or reflectivity weighting are neglected (see first three lines in Table 2). Of course this conclusion is valid only if elevation angles are small, which is the case here but also for the radars that compose the ARAMIS network. It is also shown that when the vertical beam broadening is taken into account, it is necessary to include the weighting by reflectivities and illuminations. Otherwise, the benefit is not substantial in comparison with an observation operator that does not take into account any of these two effects (lines 1, 3-4, and 5-6 in Table 2). As a corollary, if beam broadening or reflectivity weighting cannot be taken into account, these statistics tend to show that it is better to neglect both effects than accounting for only one of them. This hypothesis will be soon tested in the ALADIN 3Dvar by, for instance, testing the simplest configuration tested here (E_{-fsvb} in Table 1).

5 Conclusion

The French operational ALADIN 3Dvar has been used to simulate radial velocities from the ARAMIS Doppler radar network, preparing their assimilation in an operational framework. For that purpose, an observation operator has been implemented in the model to compute Doppler wind from the model horizontal wind field. The first version of this operator includes horizontal and vertical interpolation in the pixel location, projection along the slanted direction of the radar beam, broadening of the radar beam. Sensitivity studies have been performed in parallel to test the respective

[1] In this case, the weighting by reflectivities vanishes.

impact of neglecting the fall speed of hydrometeors, the vertical broadening and the weighting by reflectivity and illumination. These tests seem to indicate that the error made by neglecting the fall speed is at the same order than the observation error and that neglecting one of the two latter processes is equivalent to discard both of them. Observation System Experiments using different version of the observation operator will be performed to evaluate this hypothesis in the 3Dvar soon.

Tangent linear and adjoint of the tangent linear of the observation operator described in section 3 have been coded and successfully tested. First data assimilation experiments in near real time on velocities observed by adjacent radars will hopefully be performed soon and displayed during the conference.

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